SUMMARY II

Mitch Begelman
JILA, University of Colorado

- What is the “driving science”?
  - Key problems to be solved
- What is the “selling science”?
  - Tightly argued package
- Increase of discovery space
  - Maximize potential for serendipity
- What important science do we get for “free”?
  - without compromising above or too much extra cost

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CONSISTENT?

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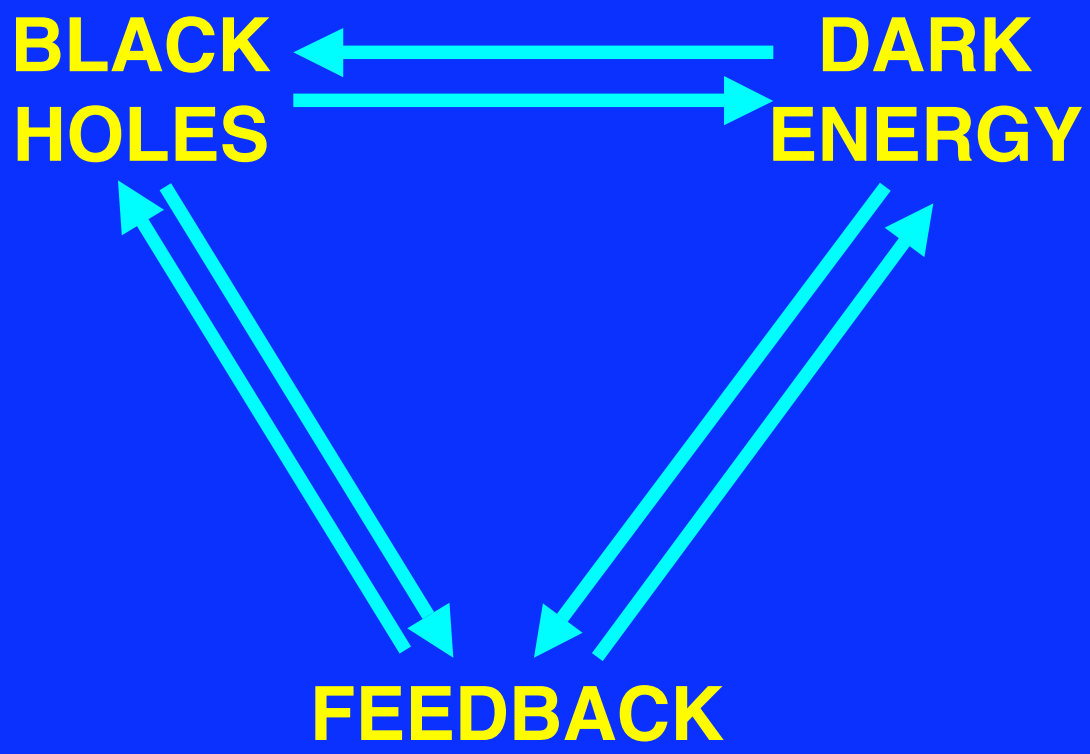
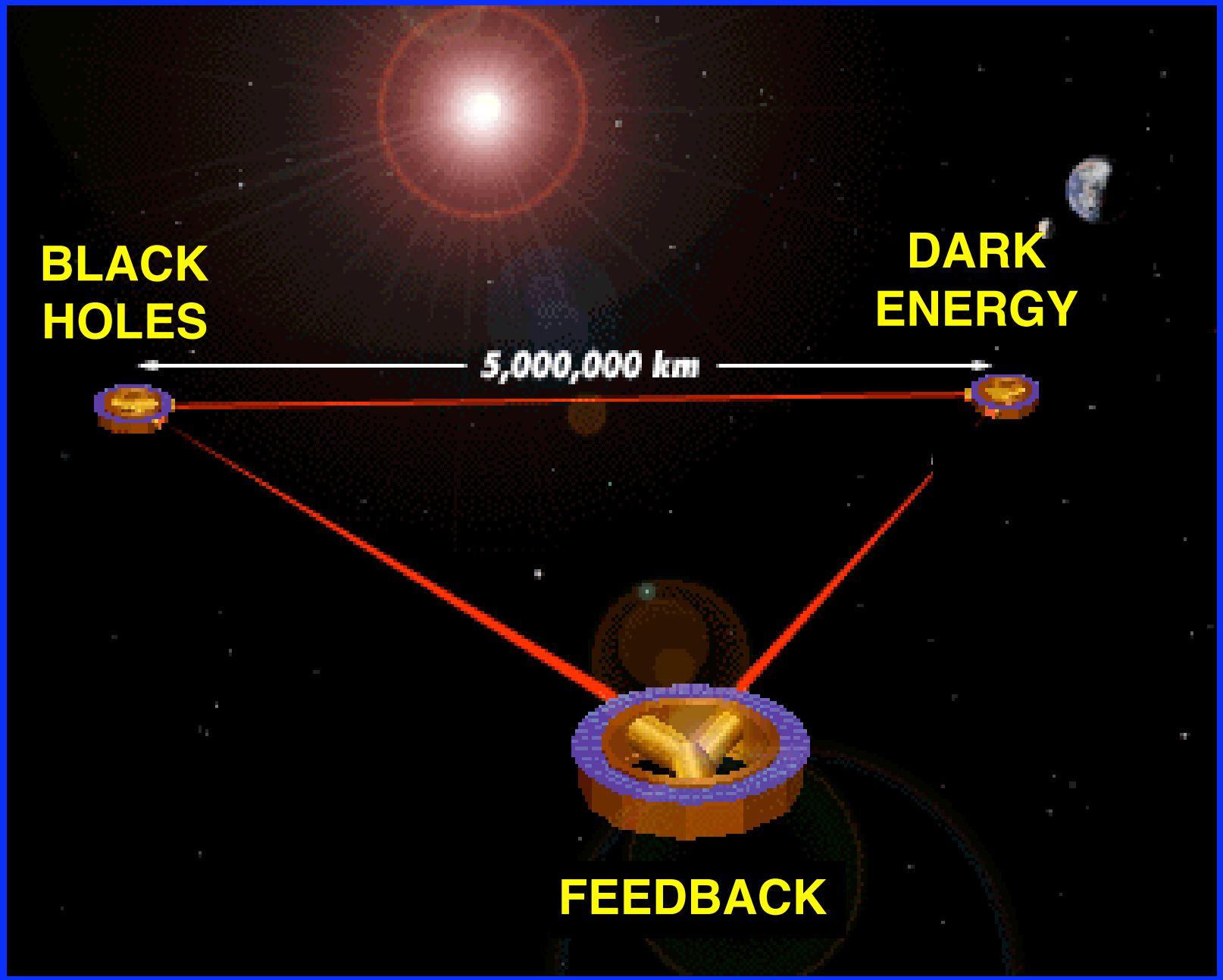
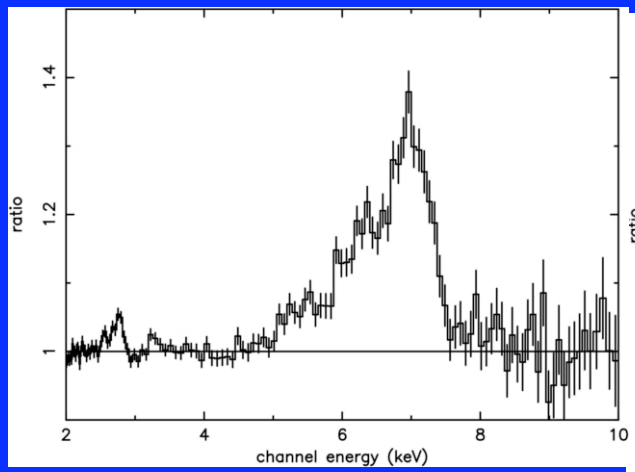
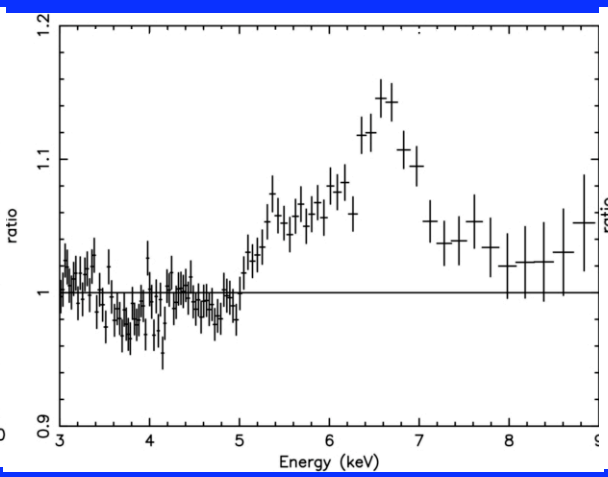

BLACK HOLES
DARK ENERGY
FEEDBACK

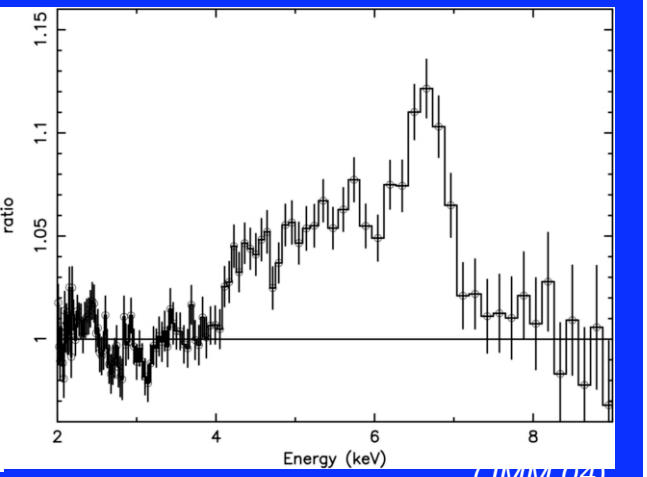

BLACK
HOLES
DARK
ENERGY
5,000,000 km
FEEDBACK

Relativistic Lines in Galactic BHs

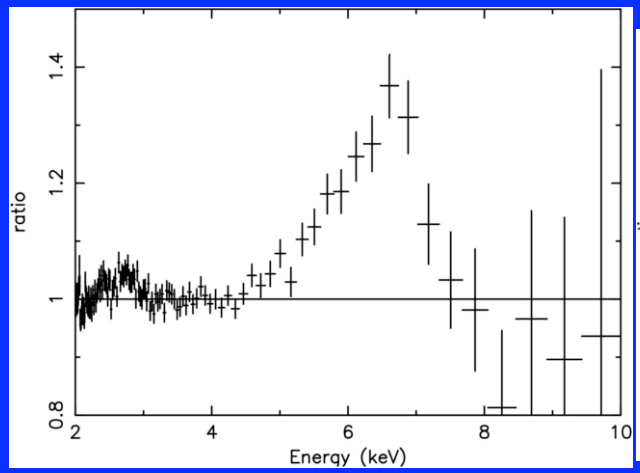
J. Miller

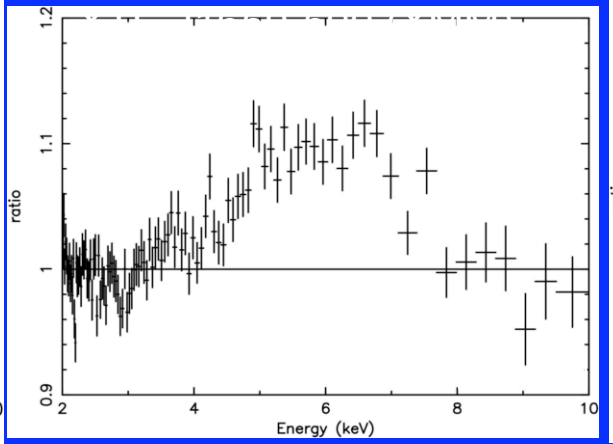


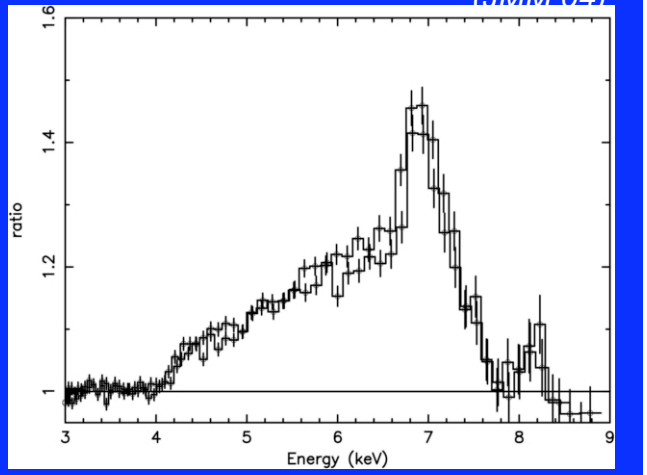




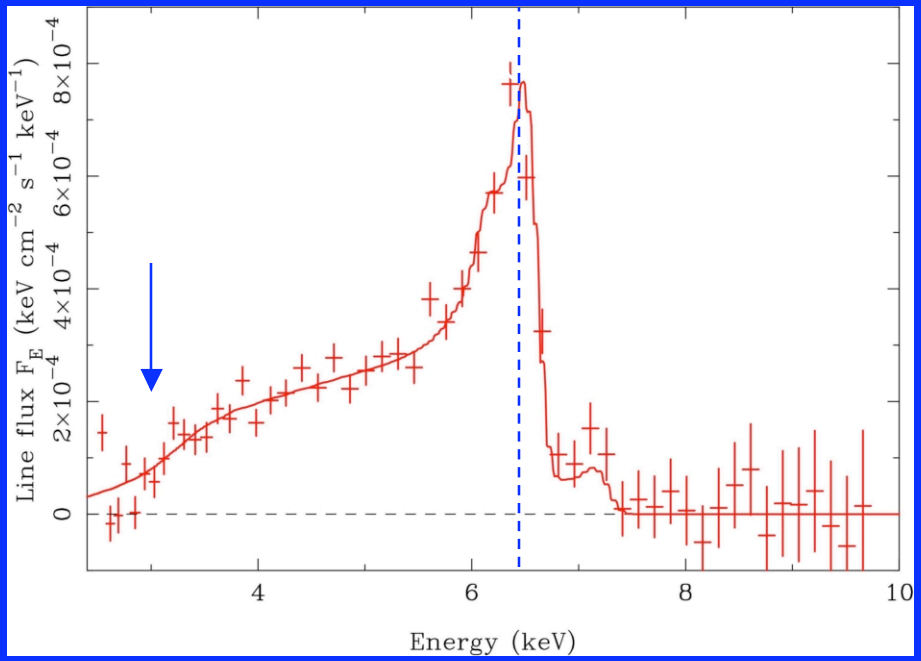
GRMHD

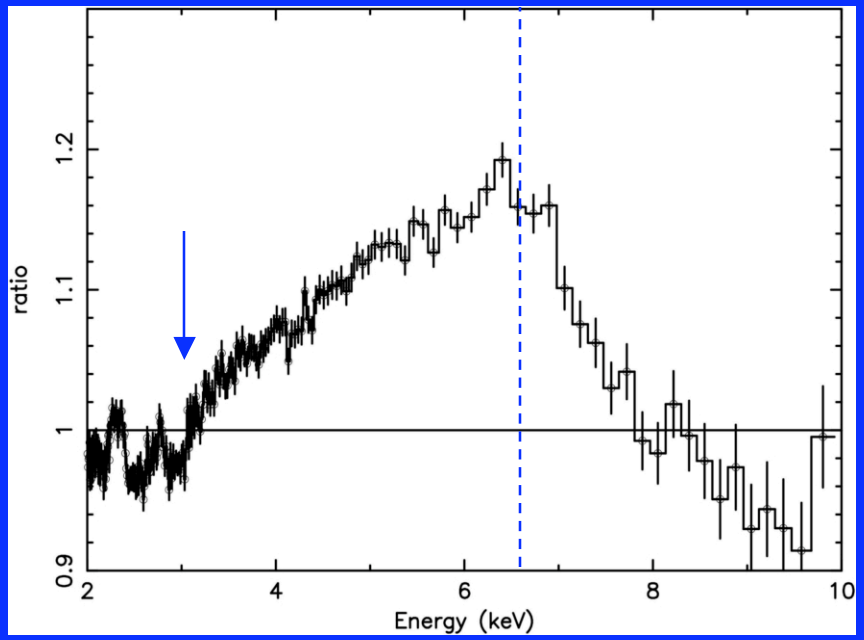






BHC – Seyfert Connections





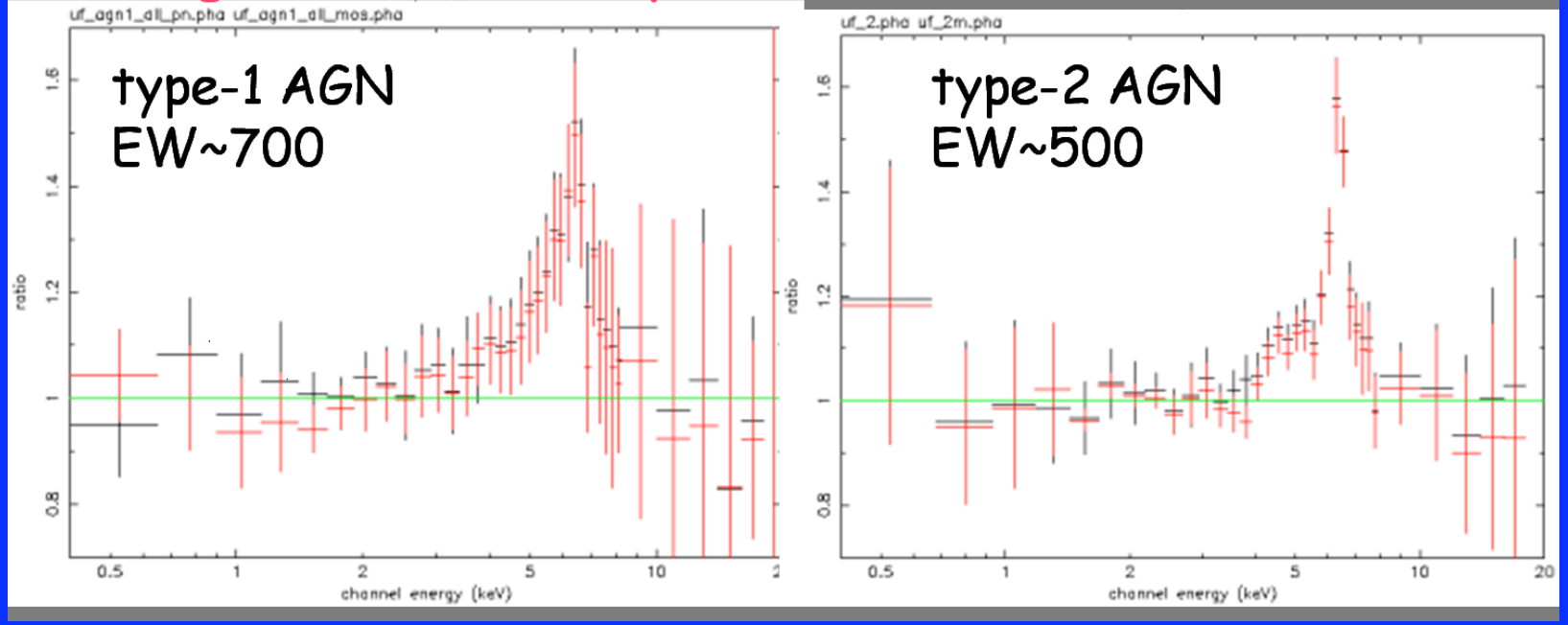
- Both lines require R_{in} ~ 2 R_g, high spin (a/M > 0.8-0.9 or so).
- Centrally concentrated emission, J(r) ~ r^{-q}, q =4-5 (q=3 expected).
- Inner accretion flows must be *remarkably* similar.

Lockman Hole

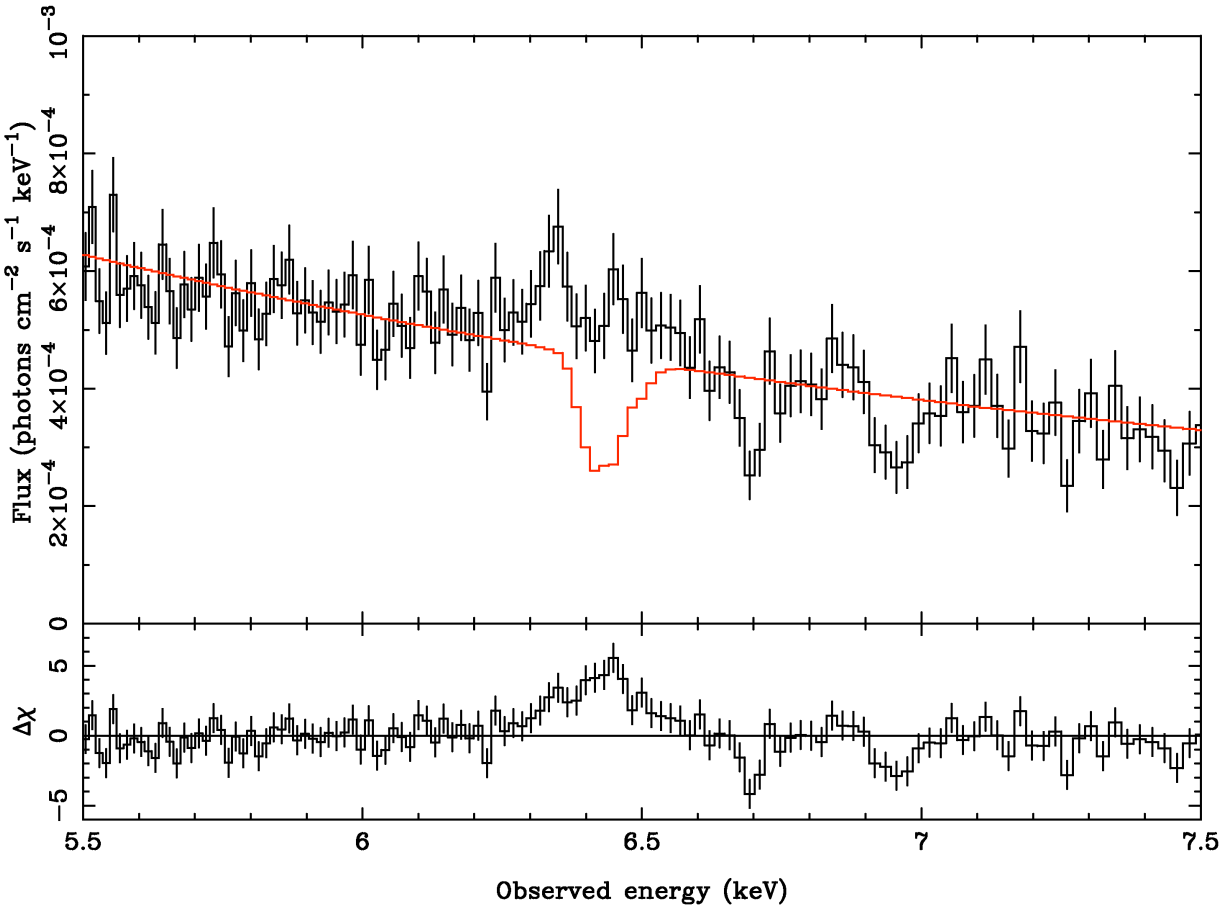
Hasinger

800 ks XMM-Newton observation

Average rest-frame spectra show relativistic Fe-lines



Streblyanskaya et al 2004



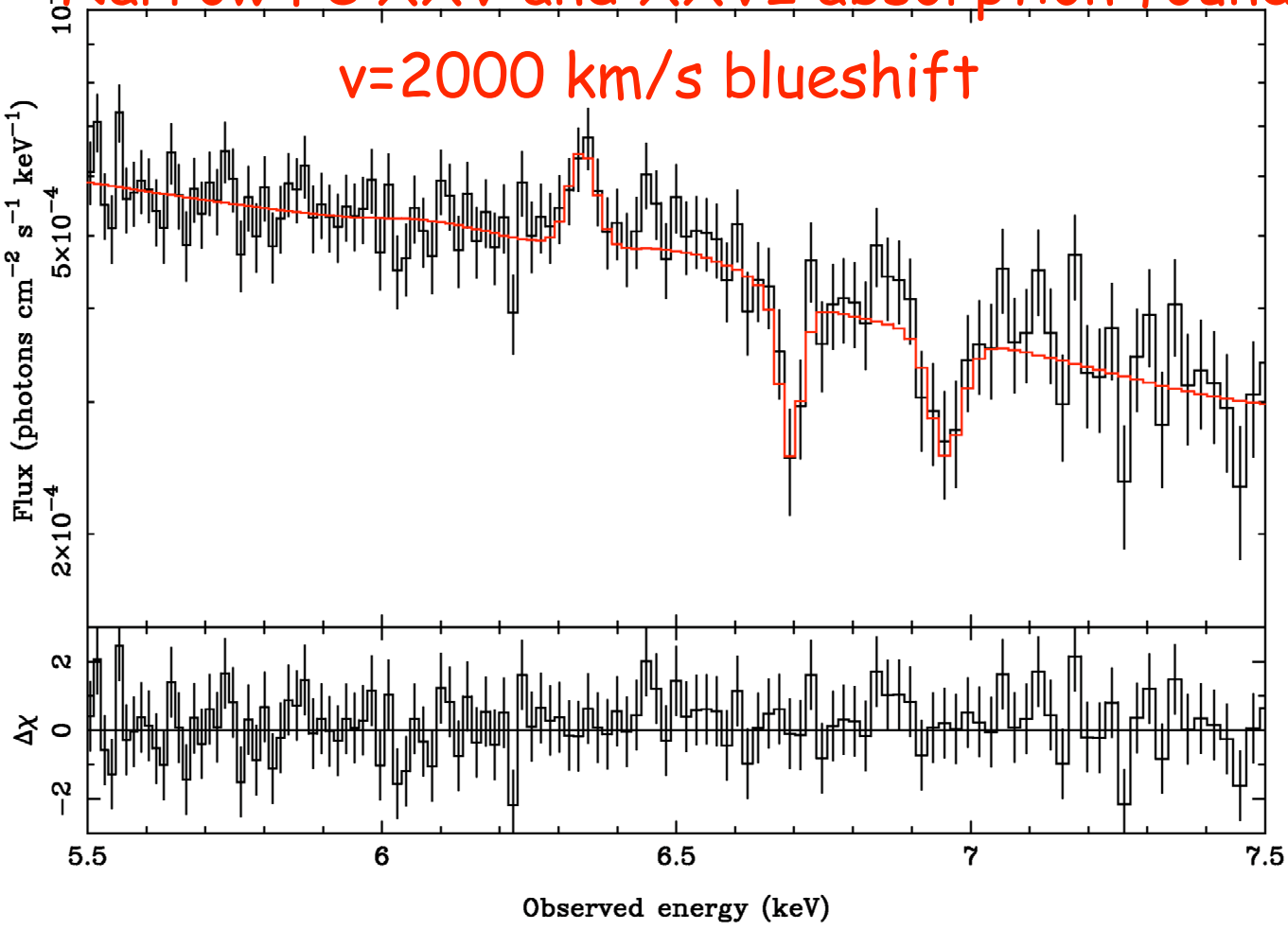
Constrains absorption by highly ionized species

MCG-6-30-15 512ks Chandra HETG; WA fit to broad line

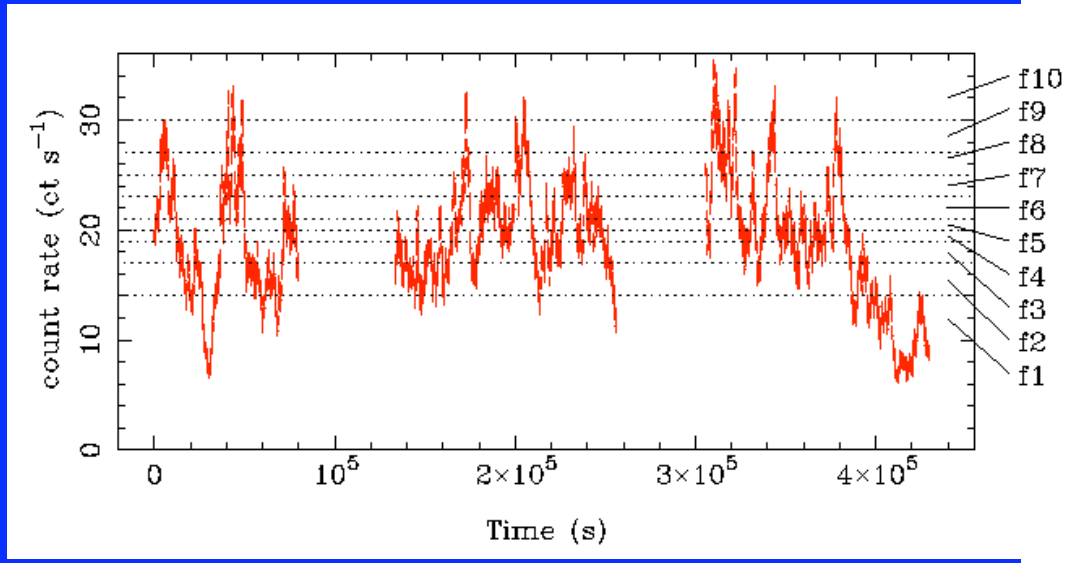
Young et al. (2005)

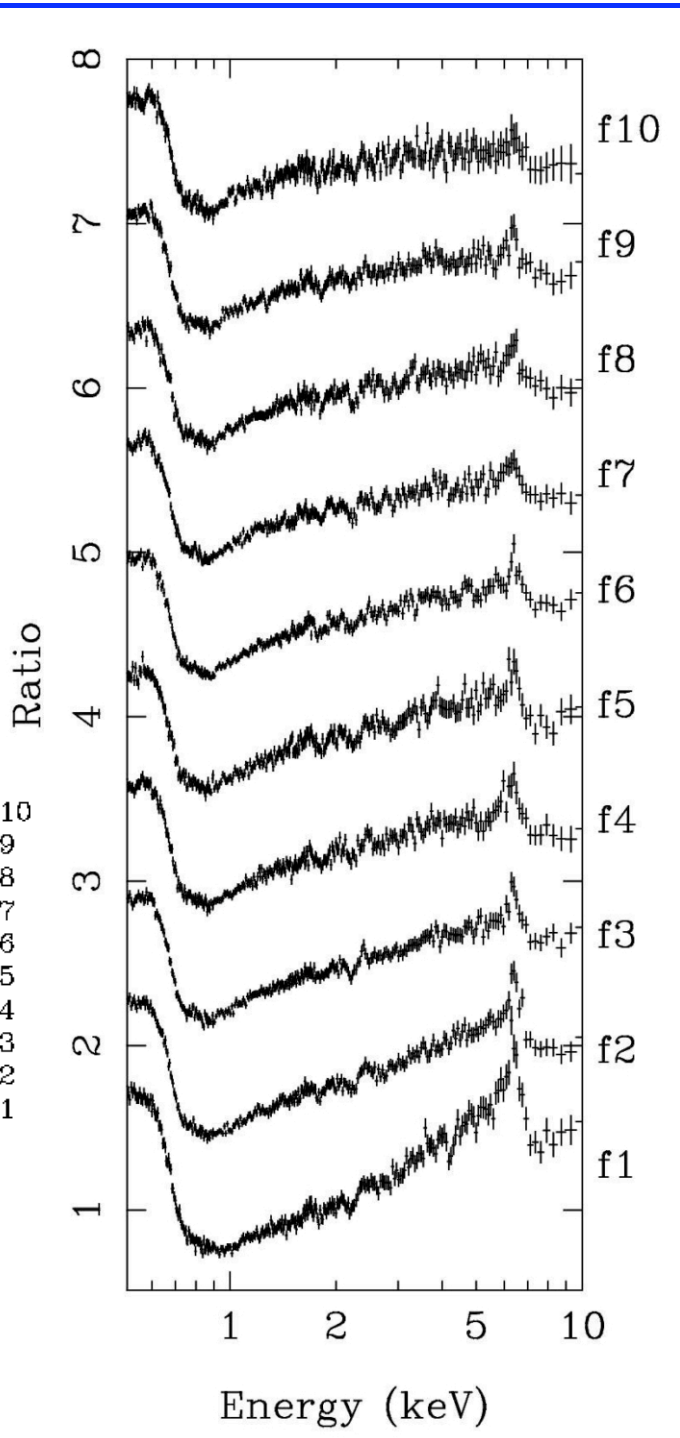
Narrow Fe XXV and XXVI absorption found

v=2000 km/s blueshift



Spectral changes seen in 10 flux slices





BLACK HOLES

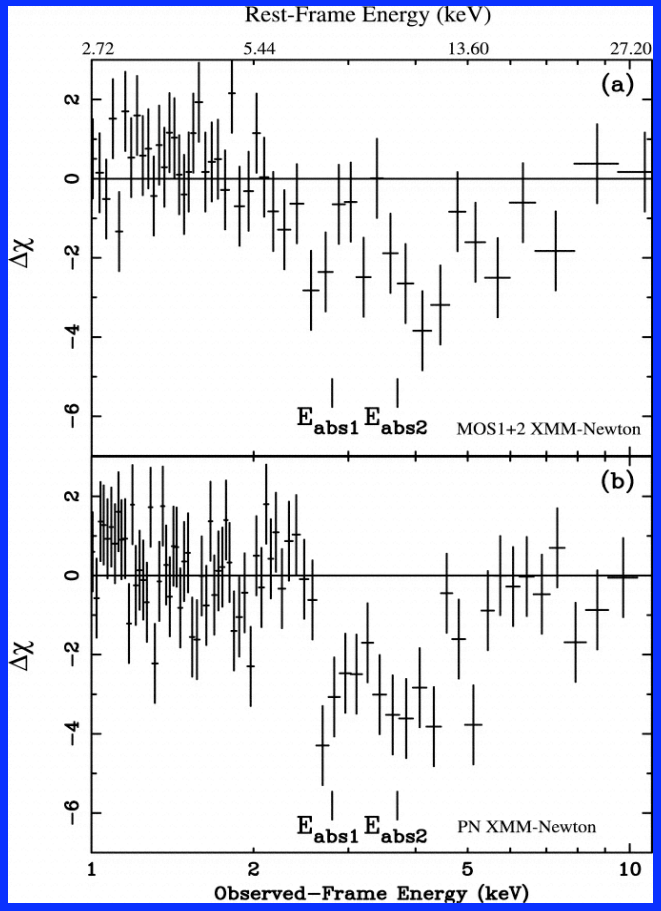
- **Strong gravity effects**
  - Frame dragging, ISCO, light-bending, QPOs
  - Extraction of spin energy
  - Mass scaling: GXRBs → AGNs
  - Check consistency with GR
- **Astrophysical phenomena**
  - Extreme MHD, radiation effects in accretion disks
  - Origin of relativistic jets
  - Black hole spin demographics
- **Links**
  - Fundamental physics
  - History of black hole growth
  - Absorption in outflows (inflows?)
  - Feedback in galaxies, clusters

Ejection/outflows: Massive outflows (iii/iii)

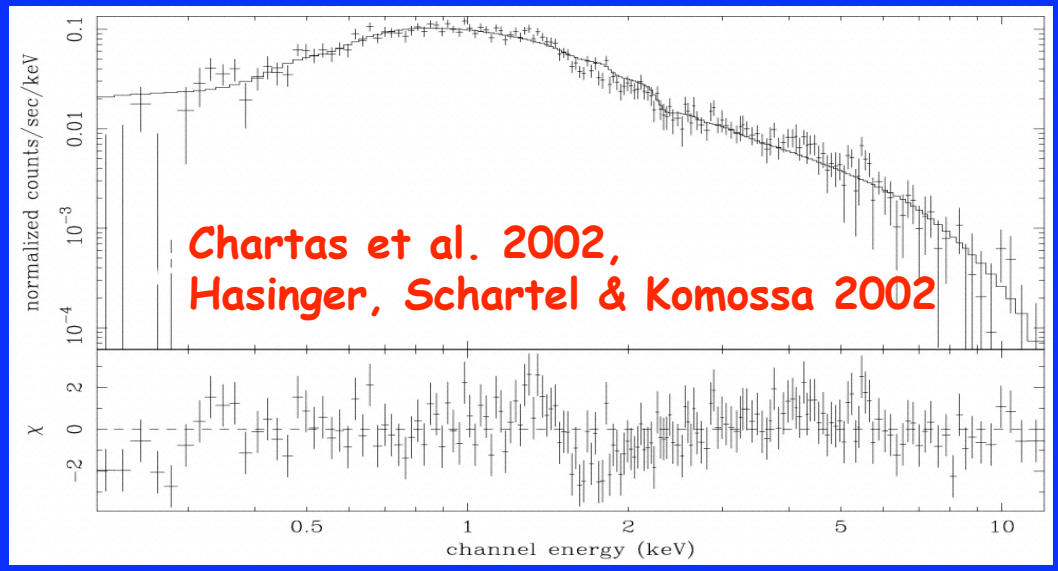
(Cappi)

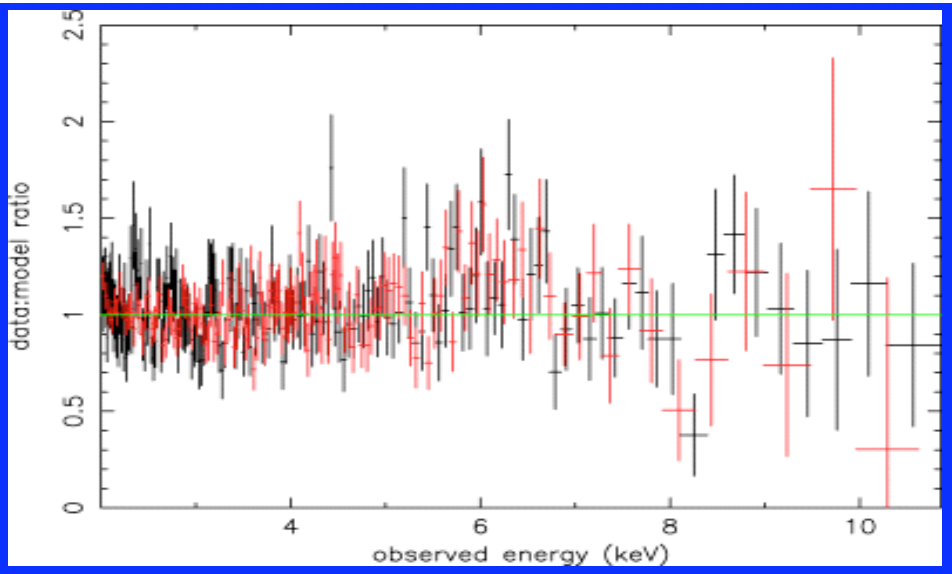
3 other cases certainly do not fit in the McKernan et al. relation

2 high-z BAL QSOs



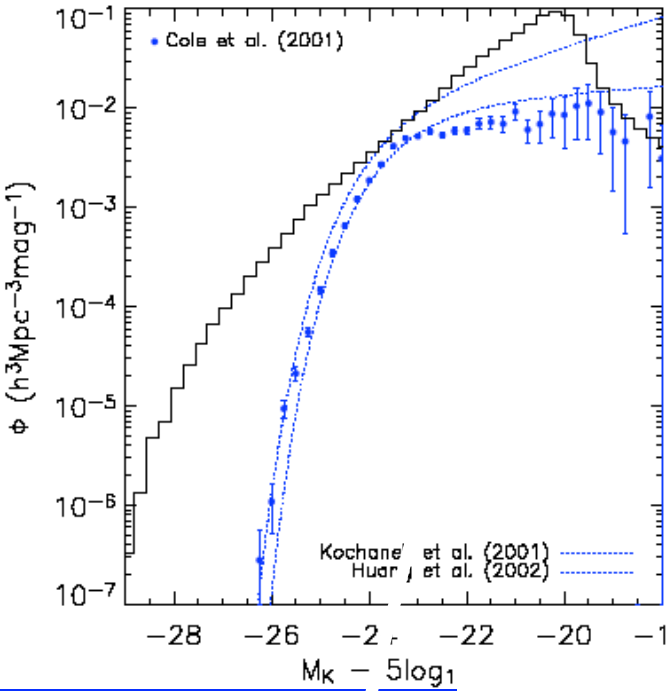
Chartas, Brandt & Gallagher, 2003





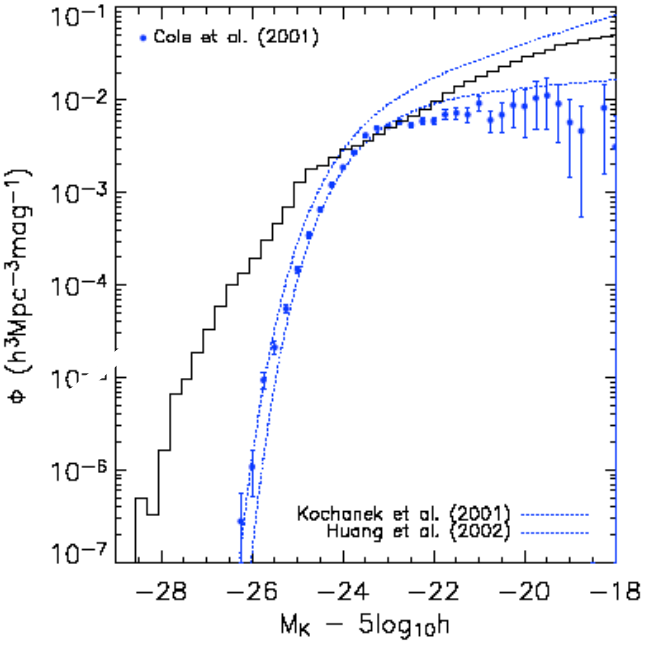
Pounds et al. 2003

N.B.: Would have been undetected at z=0...

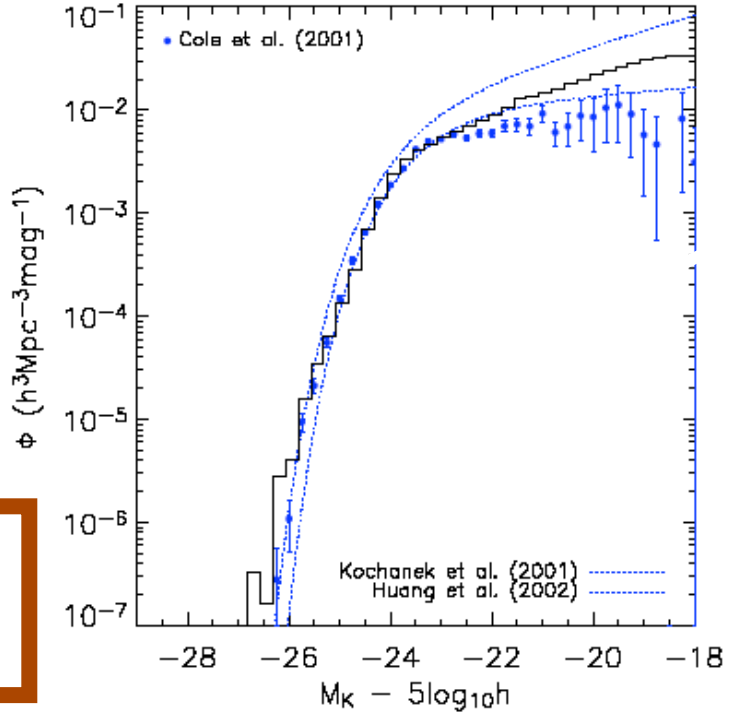


Calculation of K band galaxy luminosity function in N body simulation

Gravity+ hydrodynamics no AGN+ starburst+ reionization - **get low luminosity range 'right'**



Gravity+ hydrodynam only- **get it all wrong-** low luminosity, slope, high luminosity slope number and mass in galaxies



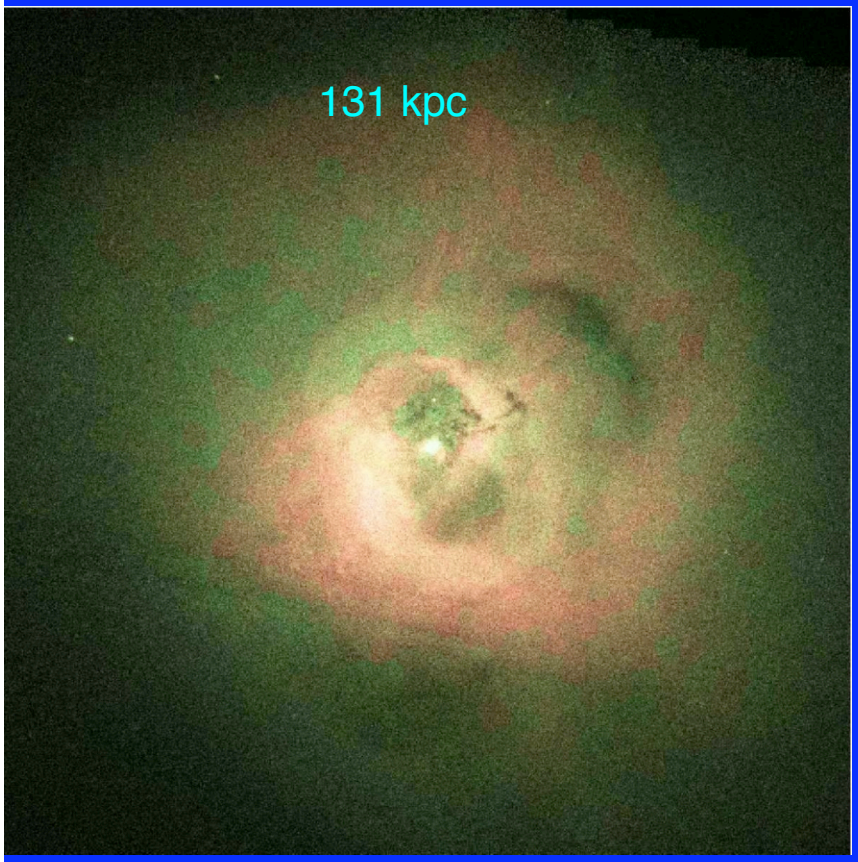
Gravity+ hydrodynamics +AGN+ starburst+ reionization - **get it all 'right'**

Thanks to V. Springel and S. White

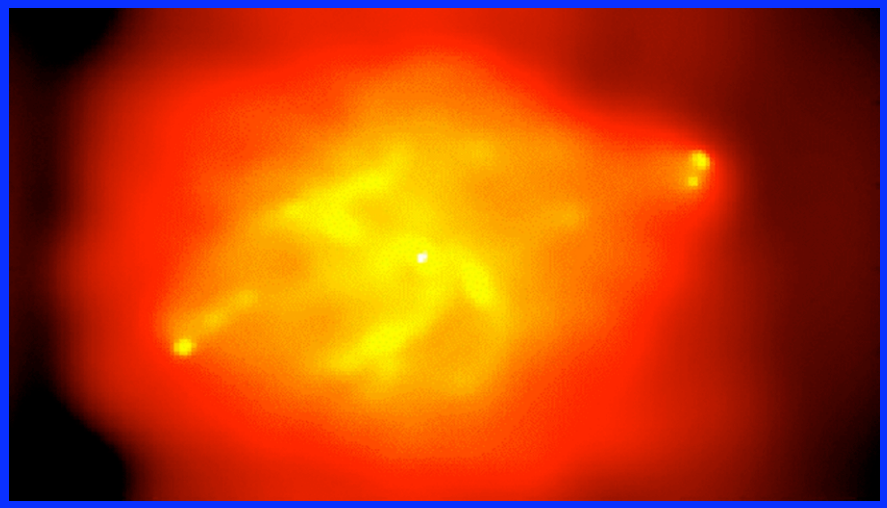
Blue lines are data black models

Direct Evidence From Chandra Images of Influence of Black holes on their Environment

X-ray temperature Map of Perseus cluster- AGN at the center



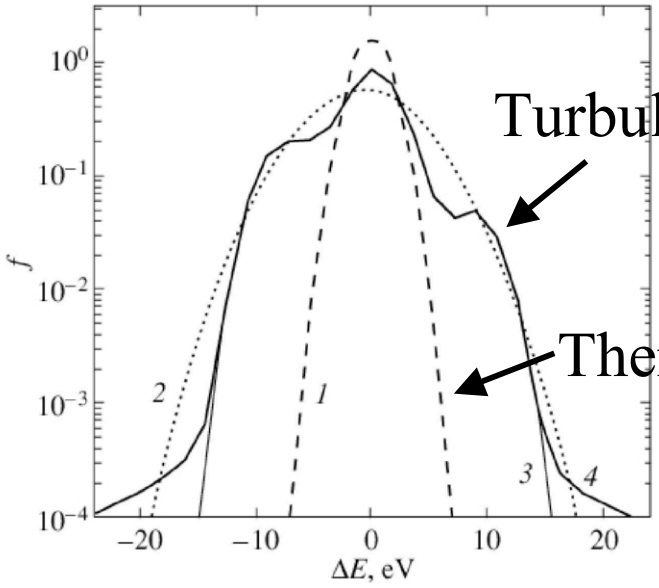
Fabian et al. 2003



- Chandra x-ray image of Cygnus-A Cluster of Galaxies with AGN in center (Wilson et al 2002)- notice the structure related to the radio source

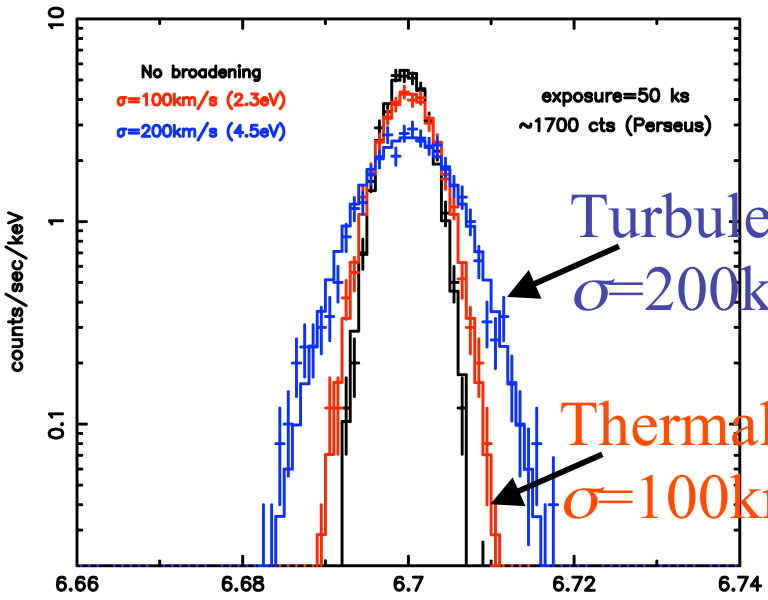
Line profile from a turbulent gas

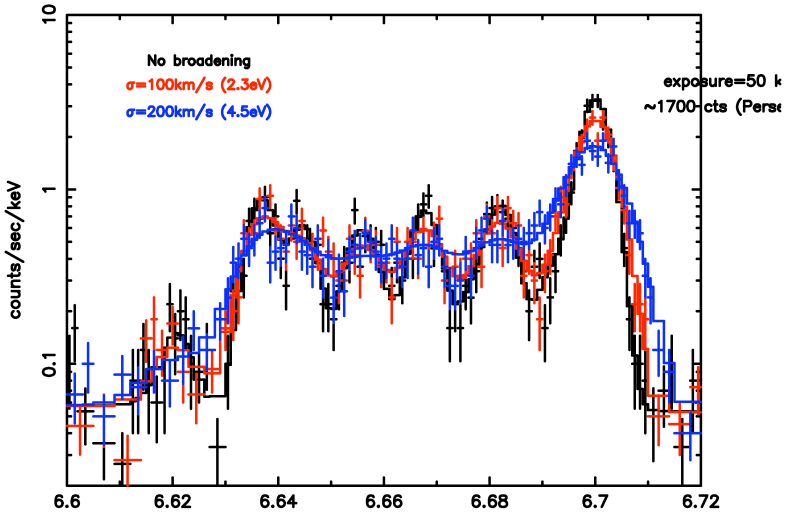
Inovamov and Sunyaev 03



Simulated XRS Fe line profile

1700 photons ⇔Perseus: 50 ksec





APEC 3 keV (1700 photons)

σ = 100 km/s (2.3 eV)

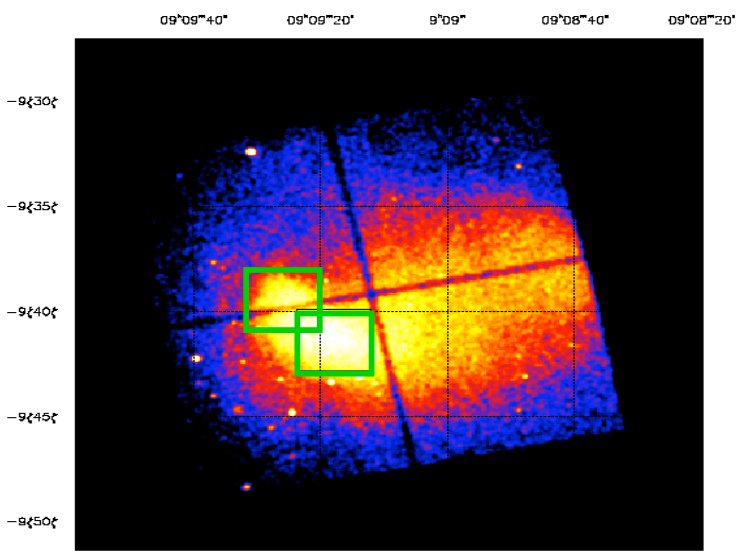
σ = 200 km/s (4.5 eV)

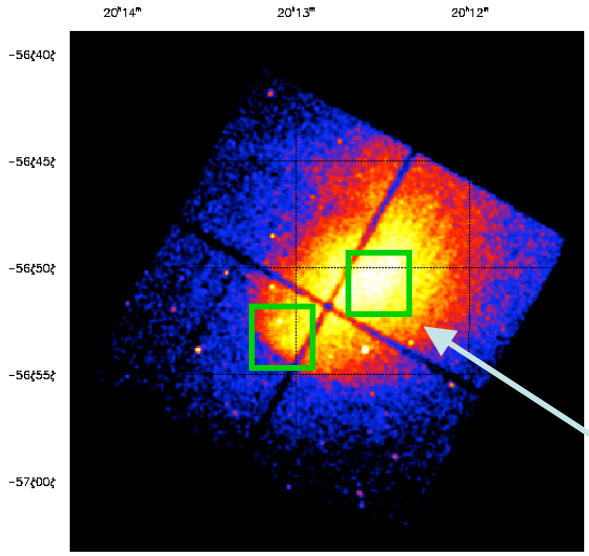
Accuracy of line width: ±0.3 eV

Cluster Velocity Field withAstroE2

XRS

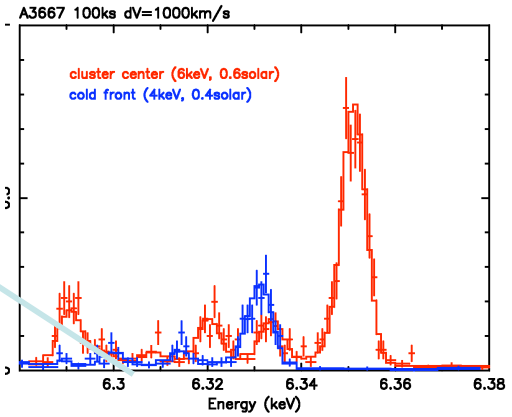
A754 (z = 0.054)

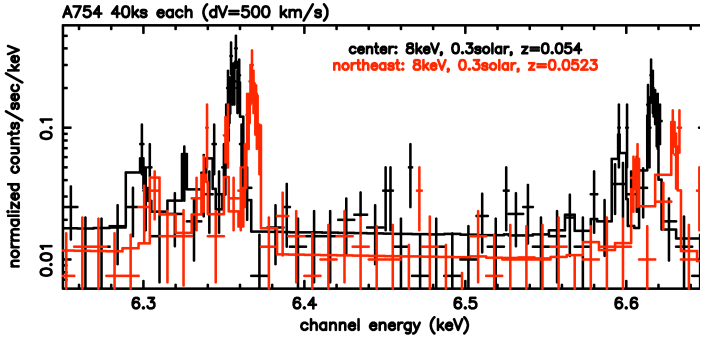




1000 km/s

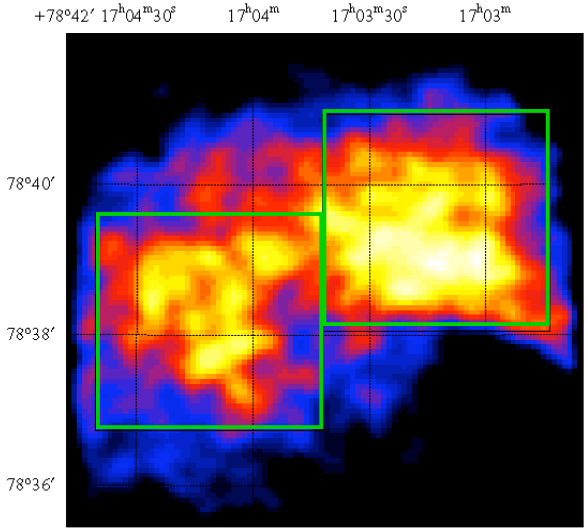
A3667 (z = 0.055)





40 ksec x 2

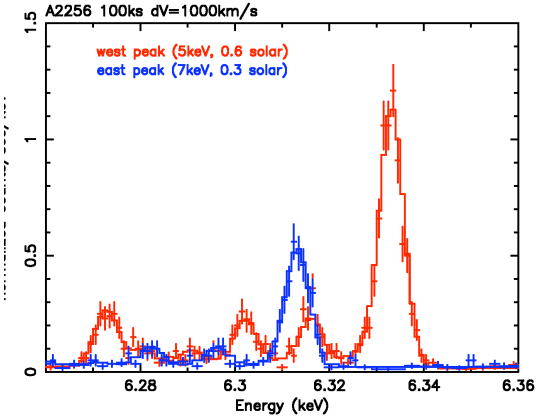
Δv= 500 km/s



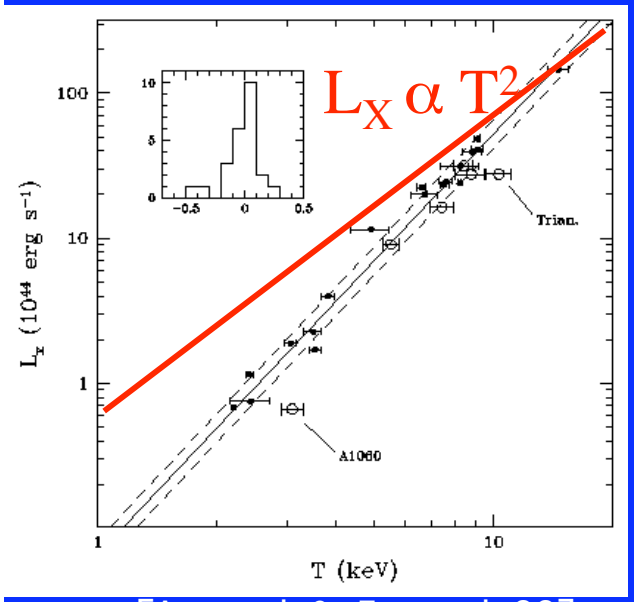
1000 km/s

100 ksec x 2

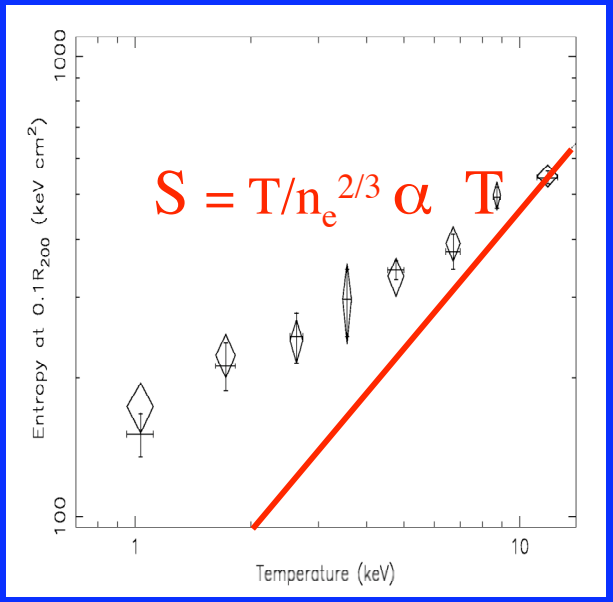
A2256 (z = 0.058)



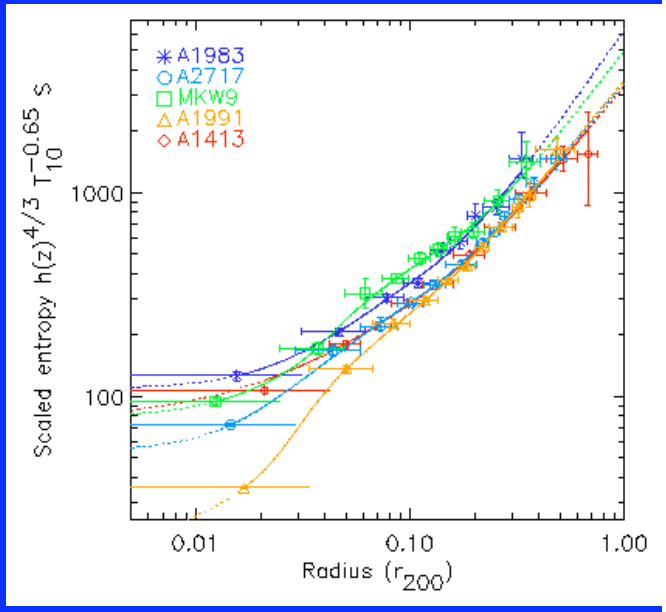
The excess entropy in nearby clusters (Arnaud)



[Arnaud & Evrard 99]



[Ponman et al, 03]



[Pratt & Arnaud, 03, 04]

Entropy excess / pure grav. heating

Relatively more in low mass systems

Self-similar entropy profiles

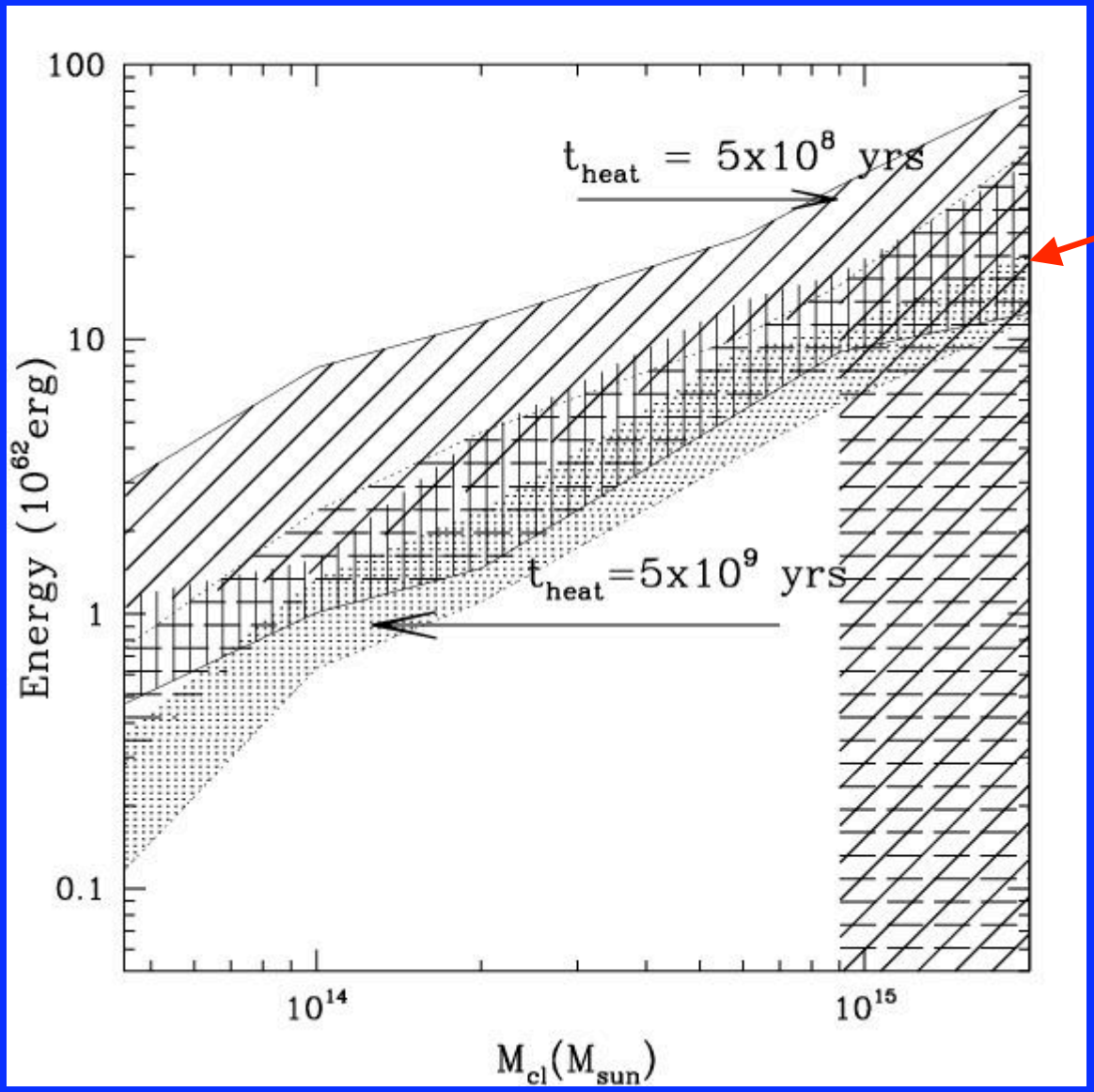
=> Not simple 'pre-heating'

Current ideas: gas history depends on grav heating

PLUS cooling and SN and/or AGN heating (and ?)

Processes not understood

Effervescent heating model

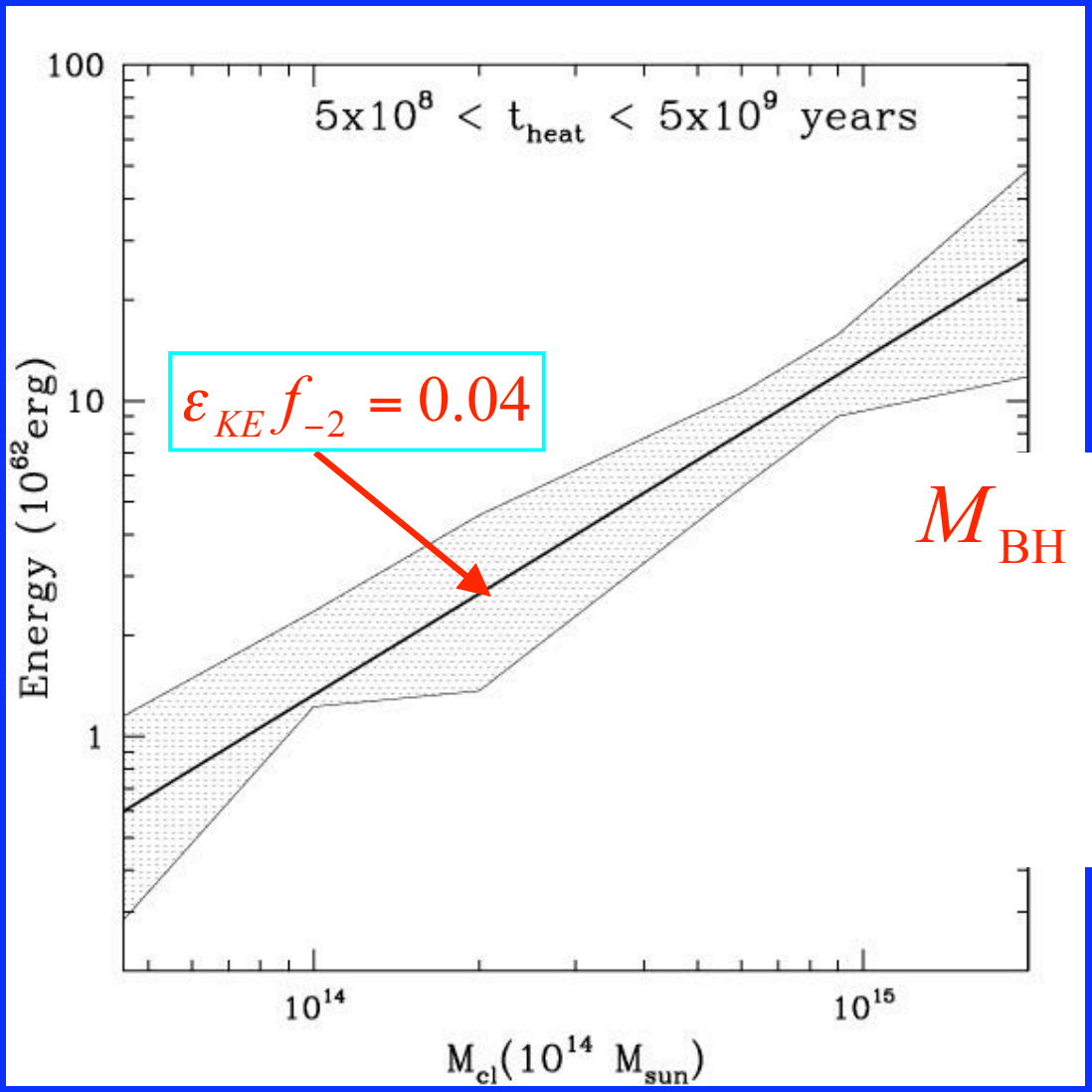


Intersection =

fit entropy data at *two* radii

Roychowdhury, Ruszkowski, Nath & Begelman 2004

$M_{\rm BH} - M_{\rm cluster}$ relation ?



$$M_{\rm BH} \approx 1.5\times10^{-3} M_{\rm bulge}$$

$$\approx 1.5\times10^{-5} f_{-2} M_{\rm cluster}$$

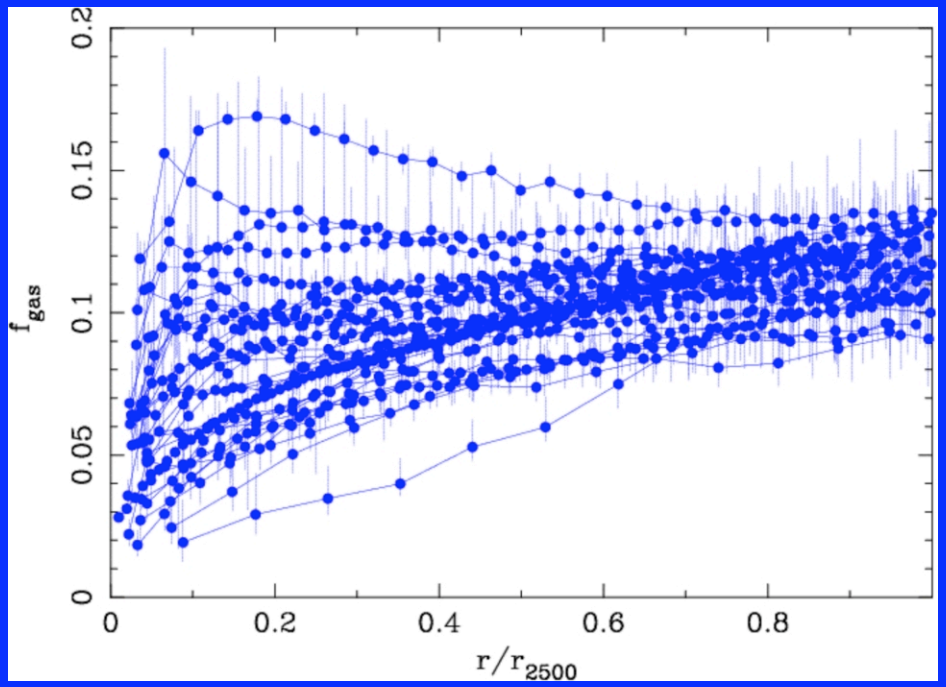
$$\approx 6\times10^{7} \varepsilon_{KE}^{-1} E_{62}\, M_{solar}$$

Roychowdhury, Ruszkowski, Nath & Begelman 2004

FEEDBACK

- **Measuring outflows**
  - Absorption line spectroscopy
  - High column-density BALs
  - Warm absorbers
- **Astrophysical phenomena**
  - Much of BH accretion energy returned to environment
  - Starburst-powered winds
  - Clusters: quenching cooling flows + raising entropy
  - Self-regulated BH growth/history of BH growth
- **Links**
  - BH physics: formation of jets and winds
  - Evolution of clusters
  - Regulation of star formation
  - Growth of structure – relation to dark energy

Chandra results on $f_{gas}(r)$ (S. Allen) (Feb 2005)



35 regular, relaxed clusters: [0.05<z<1.1, $L_X > 10^{45} h_{50}^{-2}$ erg/s , kT≥5keV]

$f_{gas}(r)$ large scatter at small radius but _ approximately universal value at r_{2500}

Weighted mean at r_{2500}

$f_{gas}(r_{2500}) = (0.1182 \pm 0.0019) h_{70}^{-1.5}$

$f_{gas}(r_{2500}) = (0.0692 \pm 0.0011) h^{-1.5}$

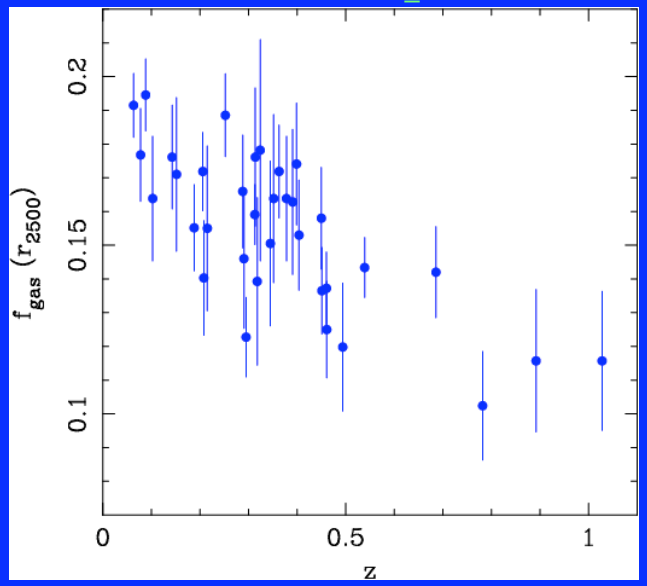
For $\Omega_b h^2 = 0.0214 \pm 0.0020$ (Kirkman et al. '03), $h = 0.72 \pm 0.08$ (Freedman et al. '01)

$$\Omega_m = \frac{(0.0437 \pm 0.0041) h_{70}^{-0.5}}{(0.1182 \pm 0.0019)(1 + 0.16 h_{70}^{0.5})} = 0.314 \pm 0.036$$

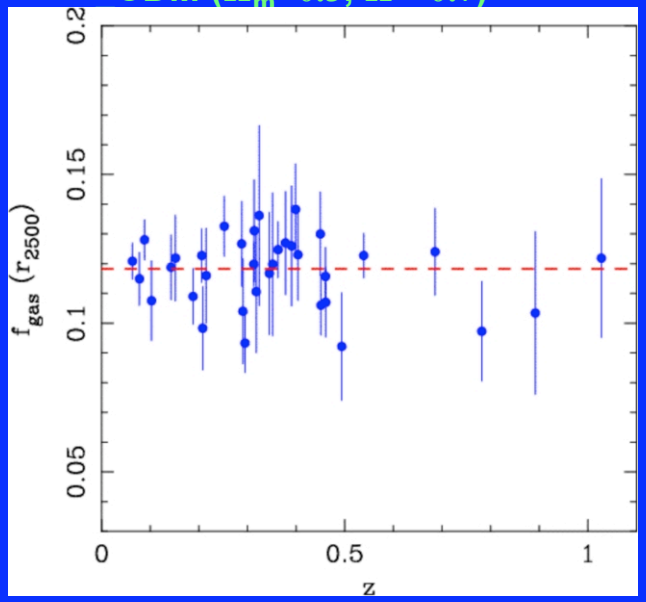
•Apparent variation of f_{gas} with redshift:

However, measured $f_{gas}(z)$ values depend upon assumed distances to clusters $f_{gas} \propto d^{1.5}$. This introduces apparent systematic variations in $f_{gas}(z)$ depending on the differences between the reference cosmology and the true cosmology.

SCDM (Ω_m=1.0, Ω_Λ=0.0)

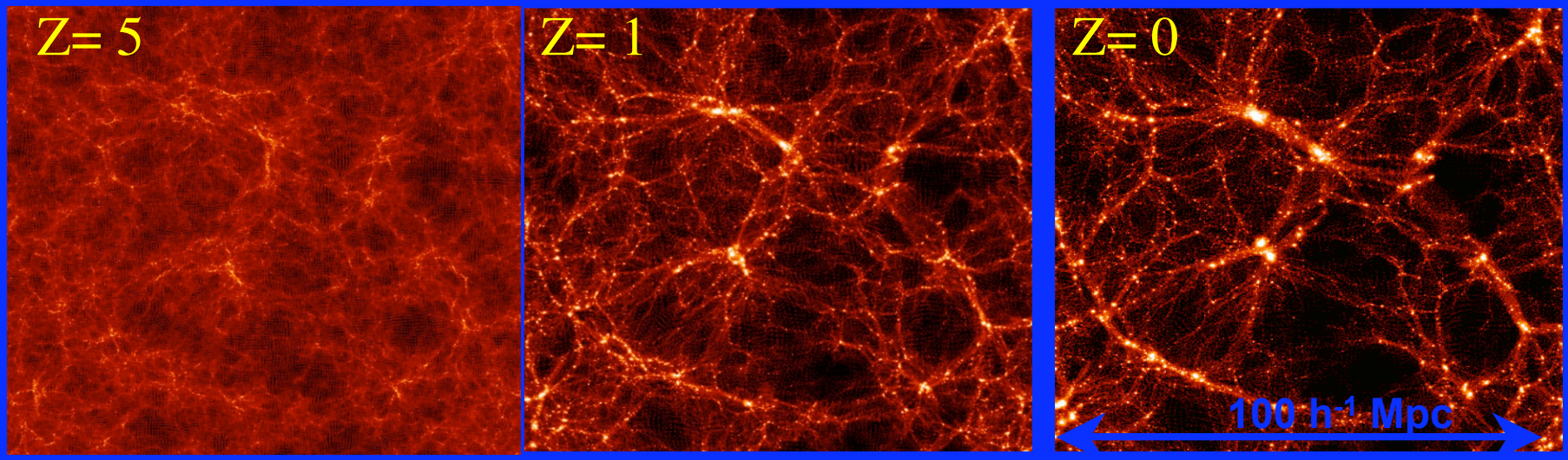


CDM (Ω_m=0.3, Ω_Λ=0.7)

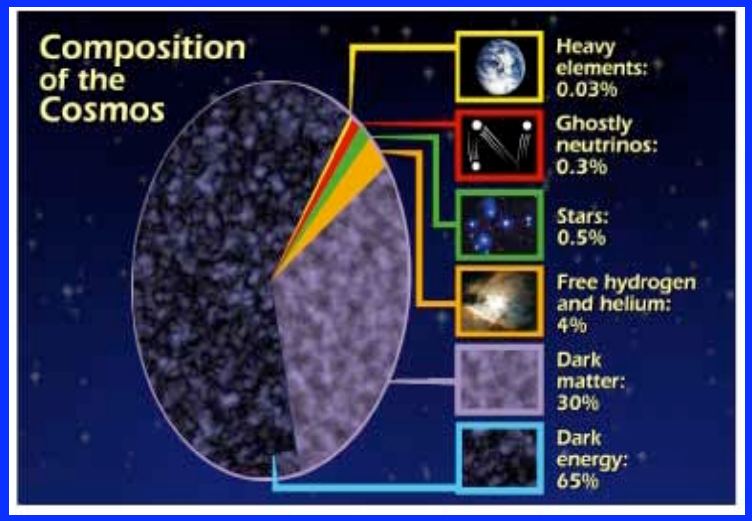


Inspection clearly favours _CDM over SCDM cosmology.

Hierarchical model of structure formation



P(k)+ΛCDM cosmology=>'standard' hierarchical scenario of structure formation



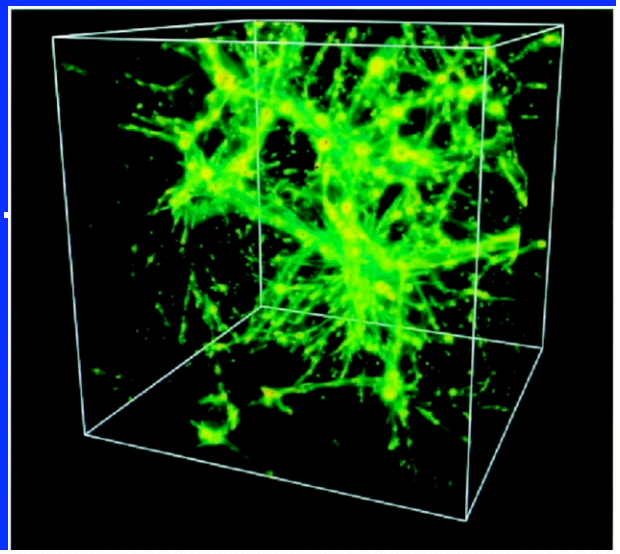
X-ray observations to study:

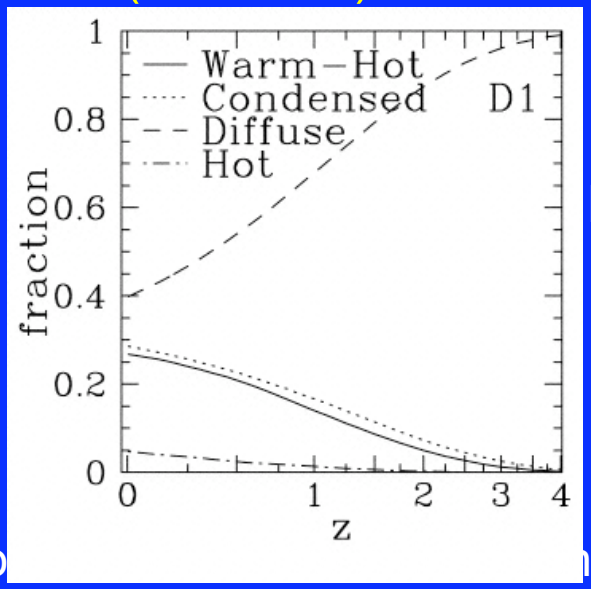
- The clusters of galaxies (DM + hot gas)
  The largest 'virialized' mass concentrations from z ~ 2 till now
- The warm/hot filaments since z ~ 1-2

The 'missing' baryons and the WHIM

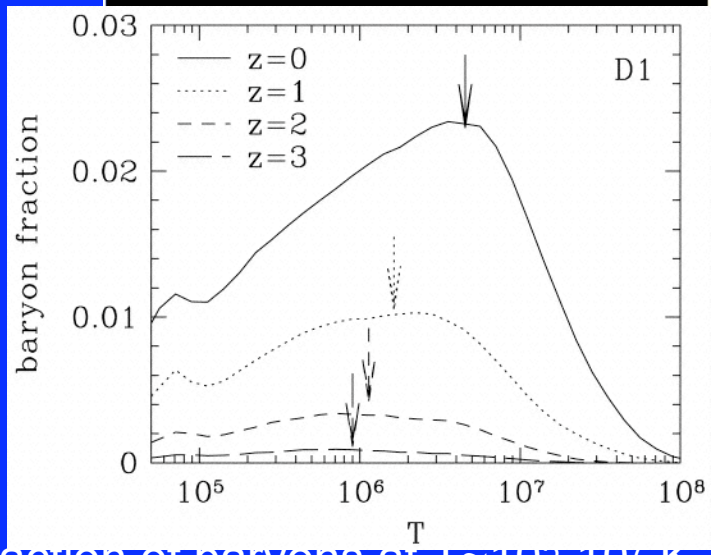
- BBN + CMB: Ω_b=(4.6±0.4)%.
  - z>2, Damped-Ly-α pop. + Ly-α clouds
  - z<2, Ly α abs. + galaxies + clusters = (2.5±0.3)%.

  ~ 50% of the baryons are 'missing'
- In WHIM (filaments) at low z ?





[Dave etal. 2001]

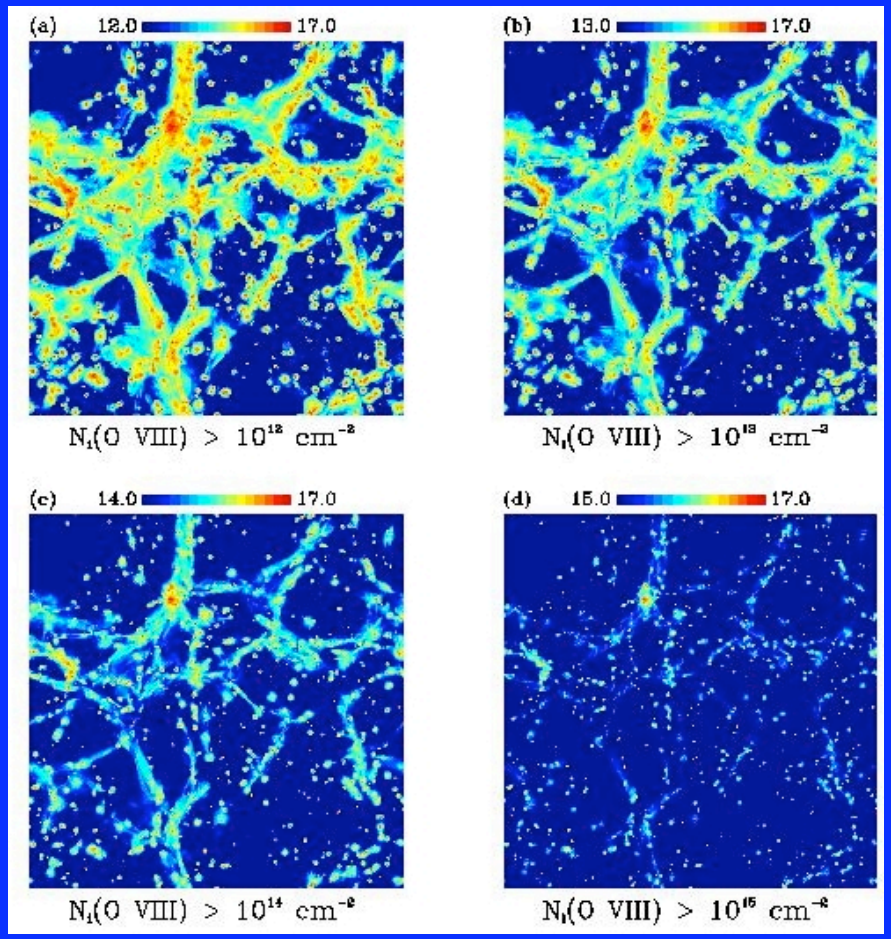


- IGM ho… …ock heating
- Extra heating might be present due to SF & AGNs

Large fraction of baryons at T~10^5-10^7 K

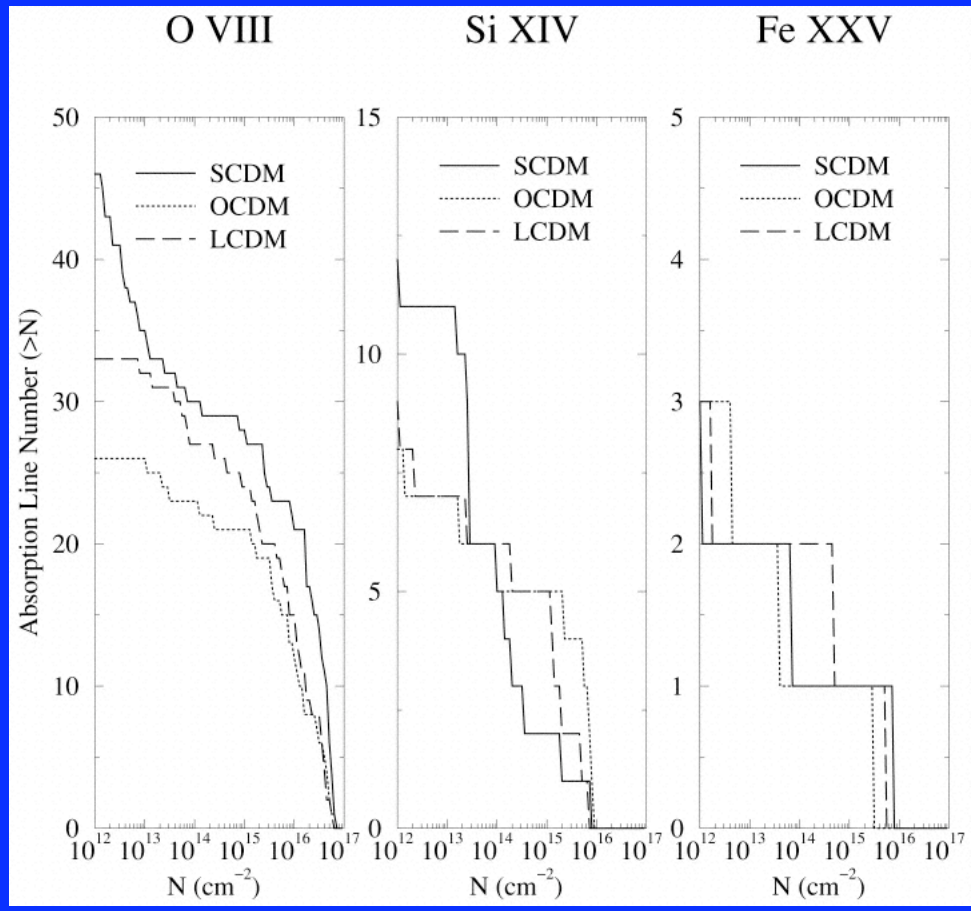
Detect (started) and study properties ($d\mathcal{N}$/dzdN, temperature, metallicity) versus z

Probe LSS/galaxy formation



[Fang, Bryan & Canizares 2002]

Column densities

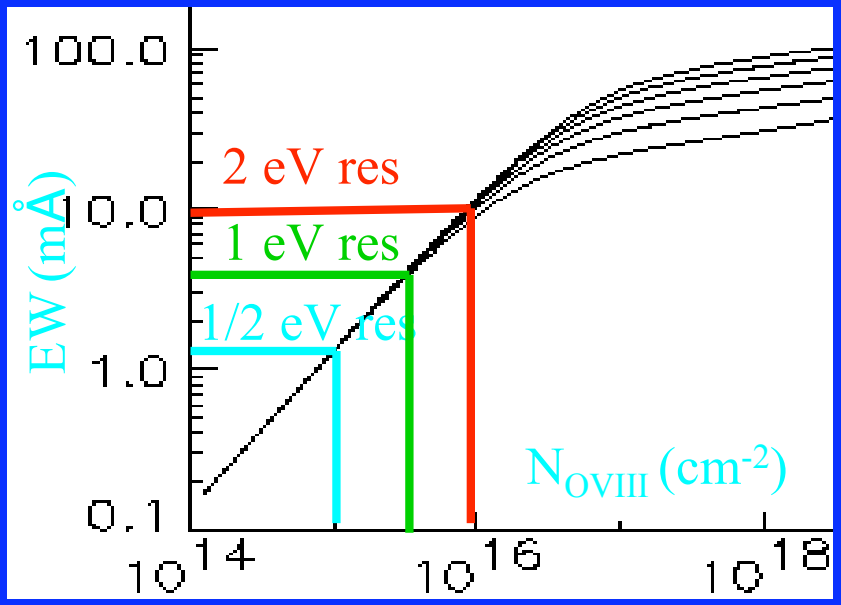


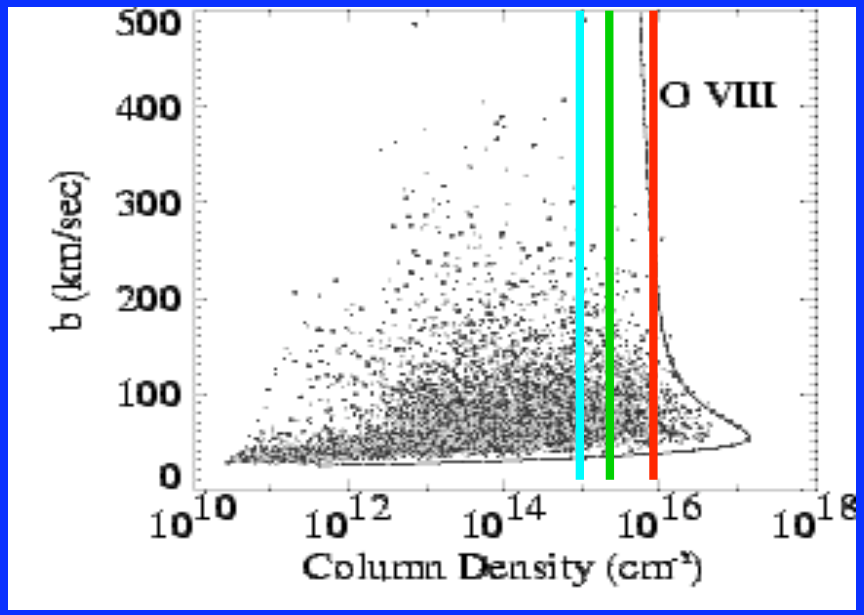
[Fang & Canizares 2002]

Distributions of absorbers

Using absorption lines in X-ray

Mission requirements





(S/N) ~ 50 x $[(S_{eff}/10\ m^2)QE\ t/(100\ ks)\ S/(10^{-13}\ erg\ cm^{-2}\ s^{-1})]^{1/2}\Delta^{-1}$ (eV)

Sensitivity (EW) ~ Δ/10

Cryo imaging spect

Gratings

Δ ~1 eV

Δ ~0.1 eV

Shorter exposures

Higher z

Weaker absorbers

Broader sampling

More detailed sampling

QE~0.5-1

QE ~ 0.03

DARK ENERGY

- **Dark energy EOS**
  - Gas fraction as a precision measure?
  - Complementary to SZ; better than SZ?
- **Astrophysical phenomena**
  - Formation of structure/cosmic web
  - Cluster evolution
  - Galaxy formation/history of *formation/abundances
  - History of BH growth
- **Links**
  - Fundamental physics
  - BH physics: feedback

DRIVING SCIENCE

- **Black holes**
  - Iron lines – profiles, variability; QPOs?
  - Black hole spin demographics
  - LT effect, extraction of spin energy
  - Consistency with GR
- **Feedback, large scale structure**
  - Effects of BH growth on clusters
  - Outflows (inflows?) from absorption
  - Missing baryons
  - History of black hole growth
- **Dark energy**
  - Clusters
  - Cosmic web

OTHER SCIENCE

- **Dynamical plasmas**
  - SNR ejecta, shocks; stellar coronae, winds; ISM
  - Abundances
  - Tie-in with ICM: turbulence, transport
  - High-resolution spectroscopy w/imaging
- **Compact objects**
  - Neutron star EOS (tie-in to BH science)
  - NS QPOs (how much timing for "free"?)
- **Galaxies and their environments**
  - Starbursts, AGNs, galactic winds
  - Tie-in to feedback
  - Abundances, distribution of elements

STRAWMAN

- **Highest feasible throughput (> 5m^2?)**
  - **Faint AGNs, XRBs**
  - **Reverberation, variability**
  - **Imaging clusters**
- **Resolution better than 5”**
  - **Clusters**
  - **Confusion**
- **Spectroscopy R>1500? (resolve 200 km/s)**
  - **Feedback flows, cluster weather**
  - **Absorption lines, cosmic web (+SNe, coronae for free)**
- **FOV > 3’(?)**
  - **Clusters, filaments (imaging spectroscopy?)**
- **High energy > 20 keV**